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ABSTRACT

Space physics research that can be effectively carried out in a manned space station is discussed. Technological, economic, and political considerations will determine whether a manned capability will be available in the period starting 1975. Assuming this capability exists, a manned space station is then the obvious environment for the study of physics in and of space. The versatility afforded by the astronaut and his ability to rearrange and service equipment make his presence highly desirable in a Cosmic Ray and High Energy Physics facility.

The study of the behavior of matter in zero-gravity conditions will be benefited by the availability of an experimenter to change his program on the basis of observations. At the same time, simple packages on board the station can be used to study relativity and micrometeoroids. Studies of the magnetosphere, plasma waves, and solar interaction with the earth-moon system may be aided by launch and control of many small subsatellites from a manned station if this proves cost-effective.

Experimental packages deployed on the lunar surface by Apollo or post-Apollo missions will aid research in cosmology, and in the study of the interactions of the sun with the earth-moon system.

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PREFACE

The following Technical Memorandum was written in preparation for and support of a study, conducted by the Science and Technology Advisory Committee (STAC), of NASA's Office of Manned Space Flight on "The Uses of Manned Space Flight, 1975-1985". This study was held December 6-9, 1968, at La Jolla, California. The ideas and content of the memorandum have been discussed during its writing with certain members of STAC, and particular thanks are due Luis Alvarez for help and comments. The responsibility for the statements made, however, rests with the present authors.

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TECHNICAL MEMORANDUM

I. INTRODUCTION

The study of the physics of our space environment has been one of the most rewarding areas of space science. (Refs. 1-6) This study has been carried out thus far almost entirely with automated satellites, and this program should continue. However, as an increasing manned capability develops, we can see great potential advantages accruing to certain areas of space physics activity.

In this paper we will assume that a substantial Manned Space Station capability will be available in the post 1975 period. We expect large weight, frequent supply missions, long lifetime (not necessarily continually manned), and high reliability. The astronaut will add a degree of versatility unattainable by other systems. While some experiments can perform automatically, the presence of man is essential in the early stages. Other experiments require a degree of interaction with the subject of the type that only a scientist can provide. This is also true in space experimentation.

We will consider here the most important of the (foreseen) physics research areas that will benefit from the available manned station capabilities:

1. High Energy and Cosmic Ray Physics

2. Behavior of solids, liquids and gases in zero-gravity

3. Relativity, Cosmology and Gravitation Physics

4. Micrometeoroid measurements, Gegenschein, Zodiacal Light, and Matter at the Libration Points

5. Magnetospheric Physics and the Study of the Trapped Radiation Belts and Aurora, Wave Propagation in a Dilute Plasma, and Interaction of the solar wind with the moon

These fields will be discussed briefly with referencesprovided for more detail.

II. HIGH ENERGY AND COSMIC RAY PHYSICS

The electromagnetic radiation that reaches the solar system has been one of the most important tools for man's quest into the origin, behavior, and maybe even end of the Universe to which he belongs. Together with this radiation we are reached by a steady flux of particles, some of them with energies higher than are envisioned as being attainable on earth. The study of the energy spectrum (extending into the 10^{20} eV region), anti-matter and nuclear composition, charge spectrum, and directionality of this radiation is expected to yield invaluable insights into the age and origin of the Universe and of the elements, nuclear processes in stars, the mechanisms responsible for supernovae, and matter and magnetic field distributions in the Galaxy. (Ref. 7)

Since these particles are strongly interacting, small amounts of atmosphere create backgrounds within which the primary information can be lost. This factor, together with the long exposure time necessary to accumulate significant amounts of information regarding the high energy end of the spectrum, makes satellites the natural conveyance for the study of Cosmic Rays.

Man's search for knowledge of and control over his environment has led him into the realm of the very small, and his advances have been intimately tied to his ability to create and use sources of higher and higher energies. Cosmic rays afford one such source. While a 200 GeV proton beam should be operational early in the 70's and a 200 GeV center of mass colliding beams experimental facility could be available in the late part of that decade, cosmic rays reach well beyond the range of these machines. Relatively simple orbiting facilities could answer some extremely important questions in the field of high energy physics. We could easily measure certain correlations among transverse momentum, longitudinal momentum, multiplicity and total energy and match these measurements against predictions of the multiperipheral theory, thus settling whether it is valid or not. The measurement of the proton-proton total cross section as a function of energy, done to 5% statistics, would establish the asymptotic behavior of the interaction, another quantity of extreme significance. Proton-proton differential cross sections at high energies would settle the argument between the optical and Regge Poles theories (the former predicts that the diffraction peak stays constant, and the latter leads one to expect the peak to shrink as log E.) Another set of answers within reach is: does the transverse momentum distribution law change at very high energies? How do weak interactions behave at these energies? Are there heavy particles being created with large transverse momenta as some Earth based experiments seem to indicate?

While unmanned payloads can study cosmic rays, a relatively small increment in instrumentation, together with the versatility made available by the use of man to rearrange* and service the hardware would give us an experimental facility that would also provide vital information in the field of high energy physics in the energy region below 10^{15} eV.

Cosmic ray physics, together with the half dozen questions posed above, could be researched by use of only one major piece of equipment: a superconducting magnet of two to three meters diameter. The operation of this magnet would require either periodic supplies of liquid helium or the development of a liquid helium refrigerator or better superconducting alloys. Success in the latter two will be of momentous consequence on Earth as well as space. Complementing the magnet there would be a liquid hydrogen target and a set of instruments such as proportional wire chambers, digitized readout spark chambers, solid Cerenkov counters, plastic scintillators, etc.

A second magnet and the addition of a streamer chamber at a later time will be possible and highly desirable. It must be emphasized that the key to a versatile facility is the periodic presence of man to rearrange experiments and service the hardware as needed. Operation will be automatic.

We feel that such a space station will continue to make important contributions in the study of high energy and cosmic ray physics for the next ten to fifteen years, and the equipment, once in orbit, could be used later in other facilities.

III. BEHAVIOR OF SOLIDS, LIQUIDS, AND GASES IN ZERO-G**

Our understanding of the physics of materials can benefit in two major ways from the zero-g environment. The pressure in a fluid can be made uniform throughout the container, and structures and materials do not need to support their own weight. The uniformity of pressure in a fluid is particularly important in experiments on phase transitions and fluctuations--a field currently of wide interest. As a specific example we can cite

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* This involves aligning massive instruments to a few-micron accuracy over distances of the order of many meters.

** The "Materials Science and Processing in Space" STAC white paper covers this area in considerable detail.

the lambda transition in liquid helium, where the gravity induced pressure gradient smears the transition temperature over regions so wide that studies of thermodynamic properties cannot be made as close to the lambda point as desired. In general, phase transitions in earth-based experiments extend over a range of temperatures because the pressure varies throughout the fluid. Uniformity of pressure in a fluid may also be useful in studying the dependence of chemical reaction rates on pressure (Refs. 8-10). While gravitational energy terms are small if compared to the electromagnetic binding forces in materials, the absence of the former may produce interesting effects.

For instance, the crystal surface structure of drops allowed to solidify under zero-g conditions, free of any contact, is of long standing interest to crystallization theory. The dynamics of these drops, suspended in free fall, can also be studied.

Experiments of this type could make use of a common, man-operated, physical sciences laboratory. With such a laboratory in space, experiments that are identified late in the space station planning could be added without too much additional effort. The presence of man also permits changes in them as new directions for research are identified.

IV. RELATIVITY, COSMOLOGY, AND GRAVITATION PHYSICS

The importance of experiments in general relativity lies in the fact that they are concerned with the large scale physical laws which determine the structure and behavior of the whole universe. There are some experiments in this field which can be performed on the earth (Refs. 11-13). However, there are other experiments which can only be done in space. A few have already been identified, and further space experiments will certainly be defined in the future. Most, if not all, of the candidate experiments could probably be automated. The justification for their inclusion in manned missions is that they could be simpler (and perhaps more effective) if operated by man. Some of these experiments, and the part that man plays in them, are listed below.

A. Space Station Experiments

1. Starlight Deflection Experiment

This experiment employs a small coronagraph to measure the relativistic deflection of starlight passing near the sun with much greater precision than can be done from the earth due to atmospheric limitations. The justification for the experiment is that if it were precise enough it might discriminate between the Brans-Dicke and Einstein theories of relativity. There is some disagreement among theorists that this experiment can discriminate among different theories of gravitation,[14] for there is a heuristic derivation of this effect which is based only on the principle of equivalence and special relativity.[15] However, the validity of this type of derivation has been seriously questioned. Indeed, in the original paper by Brans and Dicke,[16] they show that their theory leads to a different value for the deflection of starlight than does Einstein's general relativity.

Thus, this is an important experiment not only because it might discriminate between two conflicting theories, but also because it may answer some theoretical questions concerning the proper way to do certain relativistic calculations. High precision is desirable, for the Brans-Dicke theory contains an adjustable parameter and the higher the experimental precision the more meaningful are the bounds that can be placed on this parameter.

A man can perform the careful collimation of the telescope which will enable it to measure star positions to the required high precision. Also, the presence of man permits film to be used as the data collecting medium, which significantly simplifies the design and data reduction.

2. Isotropy and Spectrum of the Cosmological Black-Body Radiation

Many of the possible detectors for the radiometers used in this experiment require cryogenic cooling to achieve the desired signal/noise ratio. The cryogens needed for this job will probably be available on a manned space station. Also the availability of man will enable a much simpler experiment design since the calibration procedures need not be automated. Again the presence of man will permit long-term measurements yielding good statistics.

B. Lunar Experiments

Of the many man-deployed experiments which will be developed on Apollo missions, two yield information which is useful for relativity theory: Lunar Gravimeters, and Laser Corner Reflectors.

The discovery of gravitational waves would be an extremely significant event. A sensitive Lunar Gravimeter placed on the lunar surface will provide useful selenological data and allow the moon to be used as an antenna for the detection of these waves. The availability of men on the moon in the mid-seventies will enable placement and adjustment of more advanced versions of this instrument. Manned maintenance will keep these gravimeters operating over the long periods necessary to establish whether there are a significant number of coincidences between possible gravitation wave events on the moon and on earth.

Laser Retro-Reflectors are precision optical devices which can return laser beams to the earth to enable precise tracking of the moon's motion. This information gives a variety of data including information concerning cosmological questions such as the possibility of the variation of the gravitational constant. Men will place these instruments on the moon early in the Apollo program, but replacement will be needed throughout the 1970's as the reflectors become eroded by micrometeorites. This replacement is necessary to insure that reflectors are available for the eight to ten year period needed to obtain enough data to determine if the gravitational constant G changes as the universe expands.

V. MICROMETEOROID MEASUREMENTS, ETC.

Identifying the differences between asteroid and comet material may provide clues to the history of formation of the solar system. The relative speeds between the earth and interplanetary matter are of the order of 15 Km/sec. Sample collection will consist of deploying extremely pure traps (e.g., tungsten blocks), and recovering, resealing, and delivering them to earthside laboratories. In-situ analysis by on-board ionization and mass-spectrometry may also be feasible. Manned versus unmanned operating modes should be determined by cost effectiveness, convenience and reliability.

A related field is the study of the Gegenschein, Zodiacal light, and light from the earth-moon libration points. These phenomena all consist of sunlight scattered from interplanetary material and so give clues about its distribution in the solar system. Man is quite useful in this area because the equipment required, small wide-angle cameras, is so simple. This is an example of an experiment which may not justify an unmanned launch because it is so small it can be carried into space on a manned launch at essentially no cost. Also it makes use of man's ability to calibrate and repair equipment, and to identify new targets for study and reprogram the observing schedule. A very interesting possibility is that of matter collection at the libration points (possibly by a subsatellite) which could provide data significant to studies of the origin of the solar system.

VI. MAGNETOSPHERIC PHYSICS, ETC.

The Van Allen belts, aurora, auroral precipitation, ionospheric disturbances, magnetic storms, the magnetosheath, the magnetospheric tail, the solar wind, and solar flares are all separate manifestations of a more comprehensive phenomenon which, for lack of a better name, can be called solar system weather. To date, however, they have been studied separately because initial requirements have been for detailed and specific descriptions of the morphology of these phenomena. Large numbers of unmanned satellites and space probes have been used to explore and determine just what the environment of the earth is. (The existence of the Van Allen belts was not proved until 1958, while the solar wind was first probed in 1962.) Due to the United States exploratory program, mankind now has a reasonably complete picture of his environment. What is lacking, however, is a comprehensive understanding of the interplay of all these separate phenomena and their eventual relation to the sun and solar phenomena. (Ref. 17)

It is in obtaining this synoptic view of the fundamental interaction of the earth and sun that a manned orbiting laboratory can be most useful. It seems reasonable to assume that the charting of the environment will continue to be done by highly specialized unmanned satellites because the detectors are generally small, and the desire is to have many of these in a network providing global coverage. These satellites could be taken to the manned station and then launched individually into orbit if economic considerations warrant this deployment mode.

The orbiting laboratory could conduct experiments within the magnetosphere which would provide valuable information on the dynamics of the region. Except for the Starfish and Argus events which created an artificial Van Allen belt, there have been no experiments of this type performed in space. It is possible, for example, to inject electrons into the magnetosphere and follow their motions along the megnetic field lines. It is even possible in this way to form artificial aurorae. Environment modifying experiments of this type could study wave propagation, particle diffusion, and the dynamic coupling of magnetospheric phenomena. Subsatellites offer a wide range of experimental opportunities. Controlled from the laboratory these might be used to probe regions inaccessible to the station and to study the wakes of vehicles, radio transmission characteristics, wave-particle interactions, and whistler propagation. (Ref. 18)

VII. CRITICAL ISSUES

The realization of the goals described in this paper is not dependent on major technical innovations. Neither is there a reason to expect that the goals of sections II through VI will undergo substantial changes. Implementation by manned or unmanned modes will depend on technological developments, cost, and political considerations.

High Energy and Cosmic Ray Physics must be placed on a different standing. This program is by far the most ambitious one in terms of cost, weight and power consumption. Particle detection techniques may undergo radical changes, and continuing accelerator and theoretical work could make today's questions irrelevant ten years hence. It is with these facts in mind that we present the conclusions and recommendations of section IX.

VIII. ORBITAL CONSIDERATIONS

1. High Energy and Cosmic Ray Physics: An orbit providing low radiation background is preferable but not necessary.

2. Behavior of Matter in Zero-G: Due to atmospheric drag the lowest allowable orbit will depend on the requirements of the experiment. Table I shows values calculated for the Apollo-7 command and service modules. (Ref. 19) Accelerations are given in g's and d is the distance a body would move if subjected to the respective constant acceleration for five minutes.

TABLE I

Altitude (Km)	a/g	d (cm)
200	7×10^{-4}	32.0
300	7×10^{-5}	3.2
400	1×10^{-5}	0.5

Other orbital constraints can be found in the "Materials Science and Processing in Space" STAC white paper.

3. Gravitation Physics: No orbital preference. The experiment on starlight deflection by the sun (described in Section IV) depends on observations over long periods, but not continuously; thus a sun-synchronous orbit is unnecessary.

4. Micrometeoroid Measurements: No orbital preference. Subsatellites could be used for sample collections in areas that the station does not reach.

5. Magnetospheric Physics: No orbital preference for the station. It would be used to launch and service small probes that will be part of a global network.

IX. CONCLUSIONS AND RECOMMENDATIONS

We feel that if technology, cost considerations, and/or national goals, make available a manned capability, the presence of man in space will make possible the implementation of the programs described above. Man will deploy, calibrate and repair instrumentation as needed. His role as an observer will be particularly useful while working on the behavior of matter under zero-gravity conditions. The experimental programs described in sections III through VI could be very attractive if integrated within a large manned facility. The particle physics facility should be separate from the main station, since its electromagnetic noise output may provide an intolerable background for some of the other experiments described. Only periodic visits will be necessary, and the key to its success will be the versatility introduced by having men rearrange the hardware as necessitated by the established program and new developments in the field.

It will be necessary to follow progress in this field quite closely to insure that the programs and facilities will not be obsolete when orbited.

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Attachment
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